BOSTON UNIVERSITY
GRADUATE SCHOOL

Thesis

THE CHARACTERISTICS OF THE ENTITIES WHICH
ENTER INTO THE
STRUCTURE OF THE ATOM

by
Elizabeth Warren Richards
(A.B. Mount Holyoke College, 1918)
submitted in partial fulfilment of the
requirements for the degree of
Master of Arts
1934

Index.

THE CHARACTERISTICS OF THE ENTITIES WHICH ENTER INTO THE STRUCTURE OF THE ATOM.

A. Introduction.

1. Historical Facts about the Atom.

More than two thousand years ago the Greeks of Asia Minor pondered about the nature of matter and reached the conclusion that, although matter was divisible, there must be a limit and that that limit was the atom,- the "uncuttable". This conception was cast aside as too simple and a more complex explanation sought. The idea was not used again until centuries later, when John Dalton, in 1803, formulated the atomic theory as a scientific hypothesis. He claimed that the atom was the smallest particle of a chemical element, that, although it had never been seen, it could be weighed and measured, but that it was absolutely indivisible. As Dr. Shapley says, "Atoms were little hard chunks of matter, indivisible by grace of name and experiment and by scientific dogma".*

Probably there is no greater contrast than that furnished by the difference in outlook between the nineteenth century physicists and their twentieth century successors. In the nineteenth century they had postulated the atom,viewed the idea with smug satisfaction, and called it good. Indeed, in 1893, an eminent scientist remarked that probably all the great discoveries in science were made and future science

* Harlow Shapley, "Flights from Chaos".

would deal only with growing more familiar with these. Only two years later Wilhelm Konrad Röntgen overcame this idea by the discovery of X-rays, thereby opening up a whole new field of research, paving the way for other discoveries, and demonstrating that the story of physics was not complete.

The nineteenth century lasted just long enough to show us that the universe was not a machine in which "God was an engineer who turned the crank and made the stars and planets move in pre-determined ways". * Physical science has discarded the machine and in place of a machine-made universe, we have confusion. "An atom has become, not a thing, but a collection of events"#; mathematics, not mechanics must explain it. In the earliest decades of the twentieth century the advance in the study of the structure of the atom has been more rapid and spectacular than any like event in the history of physics. Modern scientists believe in the atom because its existence explains occurrences otherwise unexplainable; no one has disproved it, and there is a great deal of evidence for its existence. The entities with which we shall deal are, at best, convenient fictions, but they are very necessary in the study of the atom.

*Waldemar Kaempffert, "Science Changes its Mind," Forum, August, 1933.

#Idem.

2. A General Review of the Important Points of the Atomic Theory.

As early as 1911, physicists conceived of the atom as a nucleus charged with positive electricity around which electrons revolved. The net charge on the nucleus is called the atomic number. The main difference between atoms is in the way in which these extra-nuclear electrons disport themselves. Improved models are being continually presented to us, we use them for a time and then discard them as they become obsolete. There have been many different varieties of atomic theories proposed, some explaining one thing and some another until it is confusing to know which one to accept. Lord Kelvin said that the atom was a smoke ring, J. J. Thomson that it was a sphere of jelly. Rutherford's atom was a miniature solar system, while Bohr and Sommerfeld went further and calculated the orbits of the electrons. Lewis and Lagmuir thought it was a cube, while Lande called it a tetrahedron. Schroedinger said it was a diffuse atmosphere of electricity, but Heisenburg said it consisted of electrons moving now here, now there, which made up the atom's atmosphere. Now it looks as if all were wrong except Heisenburg.

The problems of the present are not solved and more appear as time goes on. No sooner had the scientists divided the hitherto indivisible atom into electrons and a nucleus than they were obliged to go on with the division. The

reasons for this are obvious:- nuclei of different atoms are so related as to suggest that they are all made up of several particles of the same kind and that particles which spring out of atoms are of such nature that they must come from the nucleus. There are at present, the following particles known:- the electron, the proton, the neutron, and the positron. Until a year or two ago the nuclei of atoms were constructed exclusively of electrons and protons. Science had just become accustomed to that idea, when these two new particles:- the neutron and the positron were discovered. They were not entirely welcome, but here they are and we must accept them.

B. The Entities.

1. The Electron.

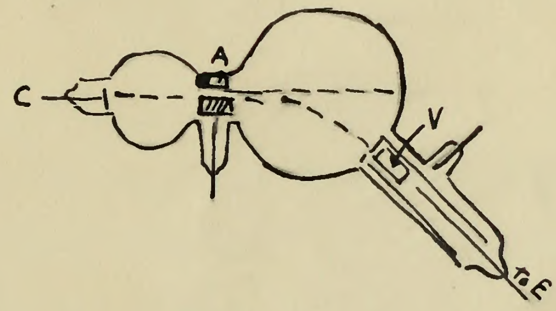
a. Its discovery and details of discovery.

As early as 1869 experiments were made with vacuum tubes and it was noticed that a strange glow occurred around the cathode. Later Sir William Crookes discovered that the cathode gave off rays which caused fluorescence. His conception was that a new state of matter, which he called radiant matter. He thought that a new world had been opened up to science,- a world where matter existed in the fourth state. The Zeeman Effect also gave evidence of the existence of a corpuscle which played an important part in the phenomena of radiation, when the source was placed in a magnetic field.

The actual discovery of the electron was due to J. J. Thomson of the Cavendish Laboratory in Cambridge, England, in 1895. He used a Crookes' tube somewhat modified. Corpuscles were found to be liberated at the negative plate of a vacuum tube when there was a sufficiently severe bombardment of the plate by positive ions. If the tube was not too highly exhausted, a relatively large number of the gas molecules were found to be present and could be ionized. If it was not too little exhausted so that a gas molecule was stopped by collision before it traveled a distance sufficient to acquire the necessary energy, then the impacts of the positive ions liberated electrons from the cathode. These shot off, repelled by

the negative plate from which they came and could be experimentally studied.

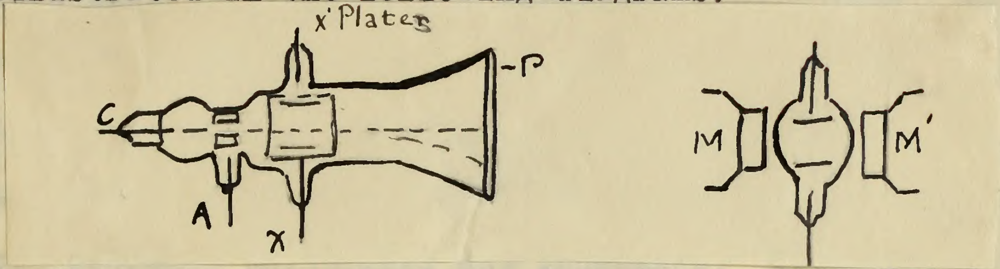
J. J. Thomson used a cathode ray tube as shown in the diagram. The anode A was hollow, the rays passed through it



and were deflected by a magnet into V. The direction of deflection proved the stream to be of negatively charged particles. They were led to the electroscope which also showed that they were negative particles, which Thomson called by the name of corpuscles.

By subjecting the beam to a field of two oppositely charged plates after deflection by a magnet, the influence of the magnetic field can be counteracted, if there is maintained a certain relation for the intensities of the electro-static field which deflects upward and the electro-magnetic field which deflects downward. Since the ratio depends upon the velocity of the moving particles, by balancing the deflection, J. J. Thomson determined the velocity of the particles as

illustrated in the following diagrams:



In the apparatus, electrons from C pass through A to the screen P. The magnets and the plates deflect the stream up or down.

b. Name and nature of the particle.

The name "electron" was suggested as early as 1891 by D. G. Johnstone Stoney as a name for the "natural unit of electricity". When the cathode stream was proved to be corpuscular, this name was adopted for those particles. The electron is an invisible, negatively charged particle known only by the effect it produces. It causes phosphorescence and fluorescence in any substance it strikes, it generates heat, it casts a shadow and can be deflected by a magnet. When it strikes substances it causes Rontgen rays. Its existence is further confirmed by the photo-electric effect where electrons are knocked out of substances by light from the visible regions of the spectrum and also by ultra-violet light.

While single electrons are shown to behave as particles, an aggregation of them exhibits properties attributed to waves. The first experiments which showed this phenomenon

were made by Davisson and Germer in April, 1925. Earlier work by Davisson and Kunsman had shown that when electrons impinged on poly-crystalline metal surfaces, the fraction scattered at an angle θ with the normal to the surfaces does not decrease uniformily as θ increases. Although incorrect conclusions were drawn from this experiment, further work along the same lines led to important discoveries.

Later Davisson and Germer were studying the distribution-in-angle of electrons scattered by poly-crystalline nickel. Accidentally it became heated to a high temperature in vacuo. The curves showing the distribution were very different from those they had studied before. The alteration proved to be due to the recrystallizing of the target of nickel in such a way that the faces were altered.

When the experiment was confined to a single octahedral surface of the nickel crystal and the beam of elcetrons was directed perpendicularly upon the surface, beams came forth from the crystal. The most striking characteristics of these beams was the correspondence of the strongest with the Laue beams which would issue from the crystal if the impinging beam was of X-rays. Whereas the refraction index for X-rays is almost exactly eqaual to one, Davisson and Germer showed that the refractive indices for the electron waves was greater than one. For the reason that the index of refraction in electron waves cannot be less than one, certain electron waves

~~cannot be less than one, certain electron waves~~ which are expected do not appear. The behavior of the electrons can be translated in terms of scattering of wave radiations by atoms of the crystal. This involves the association of wave length with the electron beam and the value turns out to be in acceptable agreement with the value h/ mv , or Planck's constant divided by the momentum of the electron.

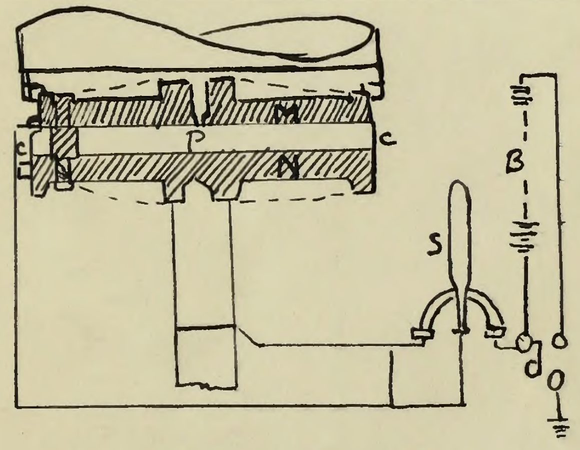
Davisson and Germer have also studied the reflection of electrons from crystals and their behavior is sufficiently comparable with that of X-rays to show that they exhibit the properties of waves.

c. Mass, dimensions, and charge.

From the date of its discovery, physicists have realized the the determination of e, the charge on the electron, was most desirable and important. J. J. Thomson sought a method, but could measure only e/m, the ratio of the charge to the mass. This was a step in the right direction, however, and the value of e/m was important in discussing the nature of the cathode stream. Since it is always the same, provided the velocity is not too great, it serves to show that we are dealing with elementary charges of electricity. Thomson's value in 1897 was $e/m = 1.8 \times 10^{7}$ electromagnetic units. Raymond T. Birge gives $e/m = (1.759 \pm 0.001) \times 10^{7}$ e.m. units. *

*Raymond T. Birge. Physical Review, Dec. 1. 1932.

Very soon Townsend devised a method for the determination of e,- a method called the cloud method. Charged molecules of air were found to act as centers of attraction for water molecules. The small drops appeared as a cloud and the number of drops could be calculated and the charge of the cloud measured. From this the charge per drop could be found. This and similar methods proved to be not very accurate and the most reliable measurements were made by Millikan in 1910. He sprayed oil in drops about 1/10,000 of an inch between two plates, M and N and one would find its way through an opening p. A stream of light made the drop visible and its motion could be observed and the time of motion found. Battery B and switches at S could make either plate positive or negative. The drops acquired charge by friction. When the



Millikan's Apparatus

plates were charged, the speed changed according to the charge. A change in velocity, therefore, would mark a change in charge. The magnitude of the electrical force could be so chosen that

the particle rose or fell or remained in the same spot for several hours at a time. When the particle did fall, its velocity could be easily and accurately measured. If there existed an elemental charge, there would be a definite minimum change in velocity. Millikan's experiment not only determined e, but gave proof of the existence of a definite elemental charge and extablished the correctness of the conception of the electron. His value for e was $4.774 \pm .005 \times 10^{-10}$ E.S. units. Raymond T. Birge gives as his value of e $(4.7683 \pm 0.0038) \times 10^{-10}$ E.S.U.*

The mass of the elcetron has been found to be 0.903×10^{-28} gm. This value is equal to $1/1839 \pm 1$ of the mass of the hydrogen atom by the spectroscopic method or $1/1847 \pm 2$ of that same mass by the deflection method. Its radius is 1/50,000 the radius of the atom or 2×10^{-13} cm.

Yet when we have stated all these facts, we know little more than before and still "something unknown is doing we don't know what." * *

*Raymond T. Birge, Physical Review. Dec. 1. 1932.

**A. S. Eddington:- The Nature of the Physical World.

2. The Proton.

a. Its discovery, when and by whom.

For some time after the discovery of the electron, nothing definite was known about the proton. In 1909, acting in accordance with the suggestion of Rutherford, Geiger and Marsden performed some experiments on the passage of alpha rays through metal sheets. In general the alpha particles were deviated little from their straight path, but tended to be spread slightly outward. A fluorescent screen allowed the two physicists to observe the impact of individual particles owing to the scintillations produced. A few isolated particles were deflected, some of them as much as 150°, an angle too great to be explained simply on the law of chance. It seemed probable, since the deflection increased with the atomic weight of the material of the foil, that at certain points some great force must be concentrated. At these points it was thought that large masses must reside.

Later experiments showed that when alpha particles were fired into hydrogen, the hydrogen nucleus was thrown forward. In the case of nitrogen, it was not the whole nucleus, but once more the hydrogen nucleus, which formed the particle produced. It can be shown similarly that a positively charged hydrogen nucleus is to be found in other nuclei. This has been considered an important constituent of the atom and it is called the proton.

b. Name and Nature of the Particle.

The name proton from the Greek πρῶτον , first,-the primary substance, was suggested by Sir Ernest Rutherford at the Cardiff meeting of the British Association in 1920. Its charge is, of course, equal to and opposite to that of the electron. It is identified with the nucleus of the hydrogen atom. It is connected with the excess positive charge on the atom and hence with its atomic number. It is very small in size compared with the electron, but its mass is much greater, nearly all the mass of the atom being concentrated in the nucleus. The protons stay permanently in the center of the atom forming the nucleus. Whenever an atom contains more protons than electrons, its total charge is said to be positive. Then it attracts more negative electricity from outside until its charge is neutral. The simplest atom, the hydrogen atom, is supposed to consist of one electron and one proton.

c. The mass, dimensions, and charge.

The radius of the proton is found to be 1/45 quadrillionth of an inch. By the spectroscopic method, this is found to be $1/1838 \pm 1$ that of the electron or by the deflection method, $1/1846 \pm 2$ that of the electron. Its charge is the same as that of the electron, but is opposite in sign. Its mass is $(1.6608 \pm .007) \times 10^{-24}$ gm.

3. The Neutron.

a. The discovery of it.

While the credit of the discovery of the neutron is given to Chadwick of the Cavendish Laboratory of Cambridge, England, in 1932, its existence was suspected in 1919, for then it was known that certain light elements, especially beryllium, yielded particles which at that time were thought to be light quanta or photons. Even in 1915, it was shown arithmetically that beryllium contained a neutron, for it should have atomic weight 8, but its atomic weight is 9. Its existence and mass were predicted by Harkness and Rutherford in 1920, both of whom assumed it to be a fundamental particle, concerned with the building of the atom. From 1920 on, the rapid development of the stages of the neutron has been unusual.

b. The Details of the discovery.

In December, 1930, Bothe and Becker at the Reichanstalt discovered penetrating rays which were produced by the bombardment of beryllium, lithium, and boron with alpha particles. They used polonium for the source of the radiation, surrounding it and the substance upon which the particles impinged by 2 mm. of zinc and brass. They used a Geiger point counter for observing the rays able to come through this shield which was sufficiently dense to stop alpha particles and X-rays. Lithium, boron, and especially beryllium showed an effect, which

they supposed was due to gamma rays or to photons.

Mme. Irene Curie Joliot and M. Joliot at L'Institut de Radium performed similar experiments using 100 millicuries of polonium with which to bombard the beryllium. They thought the rays were electro-magnetic. In January 1932, they finally interposed thin screens of substances in the paths of the rays. When the screen was of metal, no change occurred but if it was of paraffin, water or cellophane, all hydrogen-containing substances, the ionization went up instead of down. They conceived the idea that the primary rays were ejecting protons from the screen, that these protons were recoiling from high energy photons. The energy, however, and therefore their penetrating power, was found to be greater than it ought to be according to this supposition, difficulties which could not be explained.

On February 27, 1932, Chadwick reported that the particles ejected from beryllium in this manner could be made to confer great speed on protons and also on nuclei of light elements of low mass, such as lithium, helium, carbon, nitrogen, and oxygen. He concluded that the corpuscles emitted by the bombardment of beryllium with alpha particles are material particles of nearly the mass of the proton and are not protons.

c. The artificial production of neutrons.

Since the discovery of the particle, work has advanced

by leaps and bounds, until it is now possible to produce them artificially. Crane, Soltan, and Lauritsen* used two porcelain vacuum tubes, one above the other with a connecting passage between for the ions to go through. The source of high potential was a 1,000,000 volt cascade transformer and the mid-point between the tubes was connected to the half potential point of the transformer set. The ions which were produced at the inner electrode of the upper tube were accelerated successively in each tube through one-half the total potential. A magnetic field was applied to the ion beam to bend out electrons which might arrive on the reverse half cycle after which the beam was allowed to strike a two-inch target. This consisted of brass, one side of which was covered with beryllium and which could be rotated by means of a shaft to expose either the brass or the beryllium.

The electroscope used in this experiment was a quartz fiber one, 5 cm. in diameter and 8 cm. in length. In order to detect the neutrons the inside wall was coated with paraffin and the whole electroscope was inclosed in a lead cylinder of 5 cm. thickness. The center of the chamber was located about 13 cm. from the target perpendicular to the ion beam. Neutrons were supposed to penetrate the lead wall and eject hydrogen ions into the electroscope from the paraffin walls.

*Crane, Lauritsen, and Soltan:- Physical Review, Sept. 15,1933 "Artificial Production of Neutrons."

The result was that many neutrons were produced in this manner and their properties studied.

d. Name and nature of the particle.

The name neutron followed naturally from the discovery of the fact that the particle was neutral in charge. In C.T.R. Wilson's cloud chamber they are the only particles which produce no track. It is a new type of particle with which to batter the nucleus of the atom. Electrons and alpha particles are easily stopped, but the neutron evades all barriers. Fire neutrons into atoms and strange things happen. With the ejection of alpha particles, the neutron adds itself to the nucleus and is incorporated in it. New and heavier atoms are formed, or an atom splits into two others of different masses. A good example of this is in the case of the nitrogen atom, which, on being struck by a neutron splits into a helium and a boron atom.

Chadwick held at the time of his discovery that the neutron consisted of an electron and a proton. D. Meksyn says: "An electron and a proton are held together by combined attractive and repulsive forces which are in statistical equilibrium." * On this basis it is supposed that there are two possibilities for the arrangement of the electron and the proton in the neutron:- (1) the "dumbell" where the positive and negative charges are separated by a small

*D. Meksyn:- Nature, March 11, 1933, "Neutrons"

distance; (2) the "onion" type, where one kind of electricity surrounds the other.

Many physicists do not agree with this view, but consider the neutron to be a separate entity, itself an elementary particle. Proof for this is thought to be found in the collisions of neutrons with protons, where the tracks formed by the protons are measured and found to such as would be produced by a primary particle.

Whatever the nature of the neutron, there is a growing idea that atomic nuclei consist of protons and neutrons. In fact, one theory is that the nucleus consists of alpha particles, neutrons, and zero or one proton. Reasons given for these conclusions are that:- almost all neutrons exist in pairs; one proton combines with a single neutron; and light nuclei may be built up from helium nuclei, which may be formed from neutrons and protons.

e. Mass, dimensions, and charge.

All physicists seem to agree that the mass of the neutron is nearly equal to that of the hydrogen atom, which is 1.0078 on the chemical scale. It is, however, very important to know exactly by how much the neutron differs from the hydrogen atom and in what way. Curie and Joliot insist the the neutron is heavier than hydrogen and equal to 1.012. The English physicist, Chadwick, chooses as the mass 1.0067, which is slightly lighter than hydrogen. A third group at

the University of California claim to have found neutrons with a mass of 1.0006. Their calculations are based on experiments of the production of neutrons by high speed deutons. Dr. Langer of the California Institute of Technology contends that the most precise means of determining the mass of the neutron is to use the disintegration of lithium by means of deutons. In this way he sets the mass of the neutron at 1.0062. More recent experiments made by Lawrence, Livingston, and Henderson of California University point to 1.0003 as the mass of the neutron. This means that there is a great deal of energy given off in the formation of this particle. The radius of the neutron has been calculated as 1.4×10^{-13} cm. Its charge must be zero, for no charged particle could penetrate so thick a layer of matter as it can traverse.

4. The Positron

A. Discovery, by whom and when.

Although for many years the negative electron had been known and accepted as a fact, the positive electron had not put in an appearance. Two years ago Dirac in his theoretical work on the atom conceived of a positive electron. No one knew, however, how to find it nor was anyone really searching for it. It was one of those "accidental" discoveries when it came to light on August 2, 1932, when Dr. Carl D. Anderson of the California Institute of Technology was engaged in a program of cosmic ray research. The recognition of the discovery was delayed a little because some scientists held the theory that what appeared to be positive tracks might be negative tracks coming from the far side of the chamber. It was not announced, therefore until Blackett and Occhialini of the Cavendish Laboratory had confirmed the discovery.

b. The details of the discovery.

Anderson was using at the time of the discovery of the positive electron a C.T.R. Wilson cloud chamber to observe the path of the ionization particles belonging to cosmic rays. He was not the first to do this, but he made some important changes in the usual method.

Previously, a Wilson chamber had been used with its axis set up vertically, its greatest dimension horizontal, as was the easiest and most convenient way. Since the ionizing

particles of cosmic rays travel in directions close to the vertical, observations were very difficult. So the chamber used by Anderson was unusually broad, about 15 cm., and was set up with this, its greatest dimension, in a vertical plane now a common practice in cosmic ray study. His second change was even more startling:- he fitted into the inside of the chamber a plate of lead 6 mm. thick as a wall for the particles to pass through, if they had the power.

Often a magnetic field will not deflect the ionizing particles from cosmic rays, but Anderson used a powerful magnetic field of 15,000 gauss. This magnet had 800 turns of copper tubing, 1/4 inch inside and 3/8 inch outside to carry the electric current and the water for cooling.

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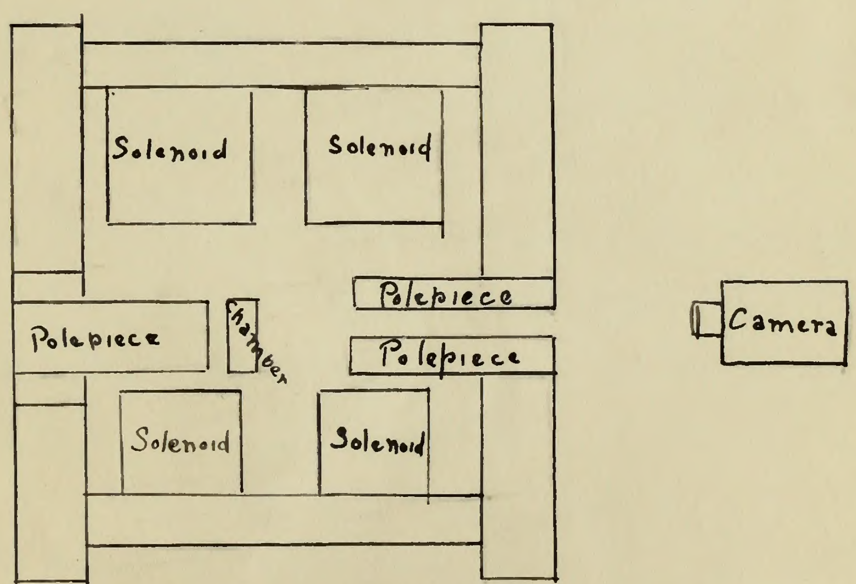


Diagram of C.D. Anderson's Apparatus

* C.D. Anderson:- "Cosmic Ray and Positive and Negative Electrons". Physical Review Sept. 1, 1932.

Separated from the chamber by an air gap of 16.5 cm. was a second pole piece with a hole through which the tracks could be easily photographed.

As Darrow says, "A Wilson chamber in cosmic ray research is more like gambling than anything else in physics; you wager the value of the photographic plate on each expansion and nineteen out of twenty times you draw a blank." * As Anderson had no device for causing the expansion to occur when most favorable, it was chance which determined the operation of his expansion chamber at just the right moment. The particle appeared to be positive as shown by its track,

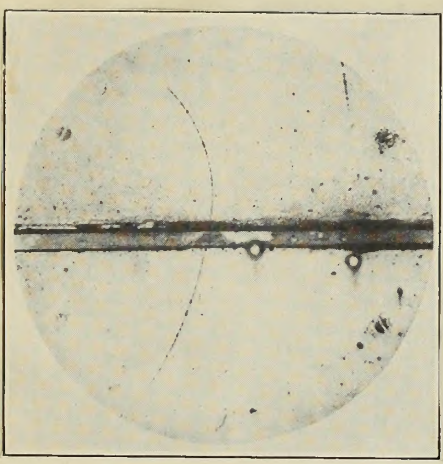


FIG. 3. THE FIRST TRACK OF A POSITIVE ELECTRON EVER RECOGNIZED. (ANDERSON.)

but the trails were longer and thinner than a proton would produce. It was concluded, therefore, that a new particle had been found.

At this time Blackett and Occhialini were also studying cosmic rays in an expansion chamber lying on its side. They were able to control the time of expansion by setting up two Geiger point counters on either side of the chamber. This resulted in showers or bursts of many trails all coming from a common point. The tracks which occurred were like electron tracks,

* K.K. Darrow, The Discovery and Early History of the Positive Electron". Scientific Monthly, Jan. 1934.

but some curved one way and some another.

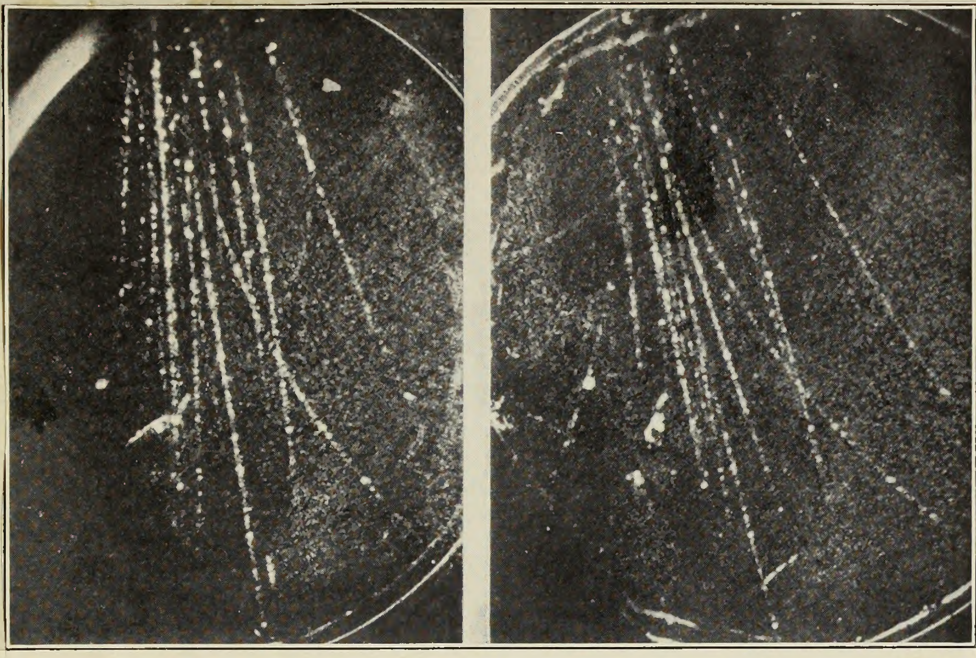


FIG. 4. A COSMIC-RAY "SHOWER" OF SOME 16 TRACKS (BLACKETT AND OCCHIALINI.)

Although this might mean that some electrons were shooting out and some in, it did not seem likely. Hence, they concluded that electrons of both signs had sprung from the explosion.

c. The artificial production of positive electrons.

Chadwick, Blackett, and Occhialini were the first to produce artificially the positive electron. Outside of the chamber they placed beryllium exposed to the bombardment of the alpha particles from polonium, or what is now known as the "Po+Be" source. Just inside they placed a lead plate on which many neutrons and photons impinged. This resulted in the production of the now familiar trails, some curved one way and some another.

The same experiment was performed by Meitner and Philipp

at Dahlem, only they placed their "Po+Be" source inside the chamber in a brass capsule. The same results occurred with a large number of positive and negative tracks.

In the spring of 1932 Joliot and Curie were photographing tracks produced by the "Po+Be" source and were greatly disturbed to note some tracks of opposite curvature to those made by electrons. Later they helped to prove the existence of the positron. Recently they have bombarded aluminum foils with alpha particles from polonium with a resulting emission of positrons. There is a like effect produced with boron and beryllium, but none with lithium showing the effect is not universal. In this way they have produced 30,000 positrons a second.

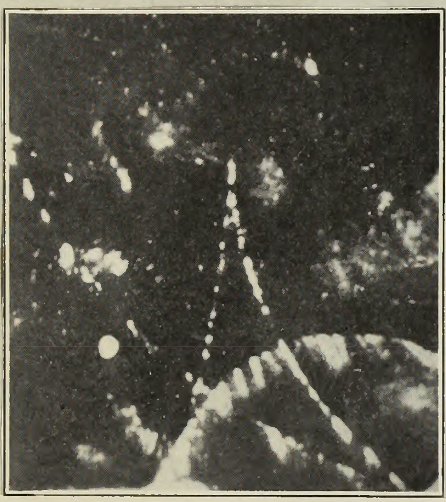


FIG. 6. TRACKS OF AN ELECTRON-PAIR ARISING IN ARGON EXPOSED TO GAMMA-RAYS, AND PROBABLY CREATED FROM A PHOTON AT ITS APPROACH TO AN ARGON NUCLEUS. (CURIE AND JOLIOT.)

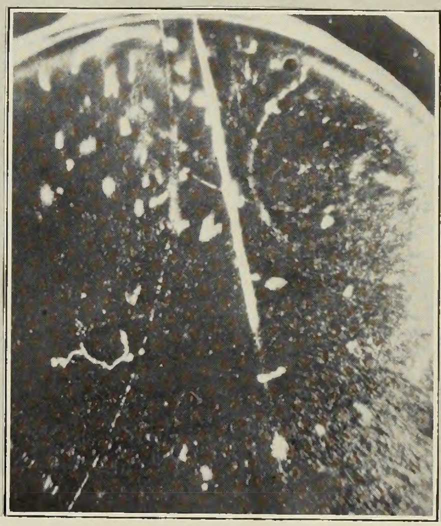


FIG. 7. TRACK OF A 3,000,000-VOLT POSITIVE ELECTRON SPRINGING FROM ALUMINIUM EXPOSED TO ALPHA-RAYS (THE LONG TRACK CONCAVE TO THE RIGHT; THE THICK TRACK IS THAT OF A PROTON, THE OTHERS OF NEGATIVE ELECTRONS. (JOLIOT AND CURIE.)

Thibaud has also produced positrons artificially from capsules of radioactive salts inclosed in silver and lead. The streams thus produced caused a fluorescent screen to give light enough to affect a photographic plate. Anderson and Neddermeyer have been successful in producing them from thorium C".

d. The name and nature of the particle.

Since this new particle had the same charge as the electron, it was, at first, called the positive electron. With characteristic elimination of the unnecessary, its name was soon shortened to the positron. Prof. Henry Dingel has recently suggested oreston as the name of the new particle, for he points out, Electra had a brother Orestes and the positive and negative electrons are like brother and sister.

The positron was proved to be positive by the curvature of its path. It was found to be of a different nature from alpha particles and protons, which are also positive, because their tracks are fat and thick, while the famous tracks of the positron are thin and slender, like electron tracks. A very fast proton might produce such a trail, but so fast a proton would not be deflected. The particle is more like the electron in everything but sign.

It had been thought that these positrons might be the product of the bombarding neutrons from Po+Be, but Joliot and Curie found that the number of positrons was not cut

down in proportion to the cutting off of the photons. It is probable, then, that the photons are chiefly if not wholly responsible for the positrons.

A positron, therefore, is supposed, according to Chadwick and his associates, to come from a transmutation of photons into a pair of electrons, one positive and the other negative. In this connection the negative electron is sometimes called the negatron. The positive and negative ought to occur in pairs. Although some positrons are apparently unpaired, this may be explained by assuming that the negatron was caught in the metal and never came out. Dr. Millikan, however, still holds to the idea that the positrons are knocked out of the nucleus.

Negatrons and positrons are thought to come from the neighborhood of the nucleus, but in their production the nucleus is unchanged and seems to act as a catalyst. It is not known surely whether the positron can be produced alone or whether it must always be connected with an electron. "The kinetic energy of the electron pair or of an isolated positron never comes within a million electron volts of that of a primary photon". * Photons of energy of less than 1,000,000 electron-volts ought not to bring about this change. Charge would be conserved in this imaginary process and so is

*K.K.Darrow, "The Discovery and Early History of the Positive Electron." Scientific Monthly, Jan. 1934.

energy.

The discovery of the electron pair "may be the last barrier which has seemed to separate the substance of electricity and matter from that of light." *

e. Mass, dimensions, and charge.

The charge of the positron is identical with that of the negatron except in sign. It is a very intricate process to determine the charge and the mass. Thibaud had applied a classical deflection theory for measuring the e/m for the positron and eventually we shall have an accurate value for this ratio. He expects a value which possibly will lie between one-half and twice and probably between one-tenth and ten times that for the negative electron. Its mass is certainly small compared with that of the proton.

*Idem. (P. 27.)

5. The Deuton.

a. Discovery of the deuton.

While the deuton is not strictly one of the entities of the atom, because of its close connection with them and especially with the proton, this account would not be complete without at least a brief reference to it.

The discovery of the deuton, the hydrogen isotope of mass two is one of the latest and most spectacular isotope discoveries. It has been known for some time that the elements are really composed of several kinds of nuclei, differing only in mass. These are known as isotopes. Each molecule and atom has a characteristic spectrum by which it can be recognized. If an atom is thought to have an isotope, it is possible to substitute the mass of the atom in formulae showing the dependence of the frequency or wave length of the lines of the spectrum upon the mass of the atom and to calculate the position of the lines of the spectrum. A photograph of the spectrum is made and the lines studied.

In this manner the isotopes of oxygen 16, having masses of 17 and 18 were discovered, and then the idea came to Birge and Menzel that there ought to be an isotope of hydrogen more massive than the kind already known. They indicated that there would be an amount in ordinary hydrogen in the ratio of 4500 : 1. At about the same time, certain discrepancies in atomic weights led Drs. Urey and Murphy of

Columbia University to look for this isotope. They thought to obtain it by liquefying large quantities of hydrogen and by fractional distillation of the same. Aided by Dr. Brickwedde of the Bureau of Standards at Washington, they were able to carry out the experiment. The evidence was found in the shifted lines in the ordinary spectrum of atomic hydrogen, which could only be explained as due to atoms of hydrogen of mass two. Thus, early in 1933, this discovery was announced.

Recent experiments by Washburn and Urey have indicated methods of preparing almost pure samples of "heavy hydrogen". Yet more recently Professor Lewis of the University of California has actually succeeded by electrolytic methods in obtaining nearly a pure state.

b. Name and nature of the particle.

All sorts of names have been offered for the nucleus of the newly discovered isotope of hydrogen which is generally called deuterium, having been so named by Professor Urey. While deuton is the most generally accepted name, others such as:- di-proton, hemi-alpha particle, and demi-helion have been proposed, all of them very clumsy names. The term deuton, suggested at the University of California has been objected to by Lord Rutherford on the grounds that there is too great a similarity between the terms <u>neutron</u> and <u>deuton</u>. He, therefore, suggests the the name "diplogen" be given to the heavy

hydrogen atom and the name "diplon" to its nucleus. This suggestion has not met with great favor in America.

This heavy hydrogen has the same chemical properties as ordinary hydrogen, but the so-called "heavy water" has a density 10 to 11 percent higher than ordinary water, and has different freezing and boiling points. It has also proved fatal to tadpoles, frogs, and other fresh water animals.

On the other hand, the deuton, or nucleus of heavy hydrogen, has proved to be a very useful article. Using it as a battering ram for the elements, it was found to be an even more effective particle than the hitherto much used alpha particle. For instance, lithium was transformed by this high speed particle into two alpha particles of greater velocity than any alpha particle from radioactive substances. Many other atoms were found to be transformed by the same means, always with the emission of alpha particles and sometimes of very fast protons.

When lithium chloride and beryllium were bombarded with deutons having energies up to 900,000 electron-volts, neutrons were produced in a far greater number than had been possible before with alpha particles. The conclusion from these experiments is that the deuton is very possibly broken up into a proton and a neutron.

c. Mass, charge, and dimensions.

The mass of the deuton has been found to be $2.0163 \pm .0004$

when referred to helium as 4.00216 and as 2.1063 $\pm$ .00008 when referred to oxygen as 16. Its mass in grams is probably about 3.31×10^{-24}, while its charge is no different from that of the ordinary proton. Its dimensions have not yet been obtained.

C. Conclusion

1. The Future of the Atom.

Seneca has said, "Nature does not allow us to explore her sanctuaries all at once. We think we are initiated, but we still are only on the threshold." * It is so with the atom, but whether it be one month or twelve, one year or a thousand, scientists will go on studying to discover all they can about the atom, their only reward the virtue of the "faithful servant" whose task is well done.

Science is news today, and there is hardly a prominent newspaper in the country which does not devote some part of its pages at least once a week to the recent discoveries in science. When we turn our attention to the atom, the changes are almost breath taking in their rapidity and scope. One sympathizes with the preacher in England who wished that there might be a halt called on research and invention for ten years, while we caught up with what had already been discovered.

We are, however, very far from calling a halt for ten years or even ten minutes. Never has there been a time when science opened up such possibilities! Never was so much machinery being prepared, so many projectiles being made ready for the breaking down of the atom's last defenese,- the nucleus. Just one instance is the preparation at the

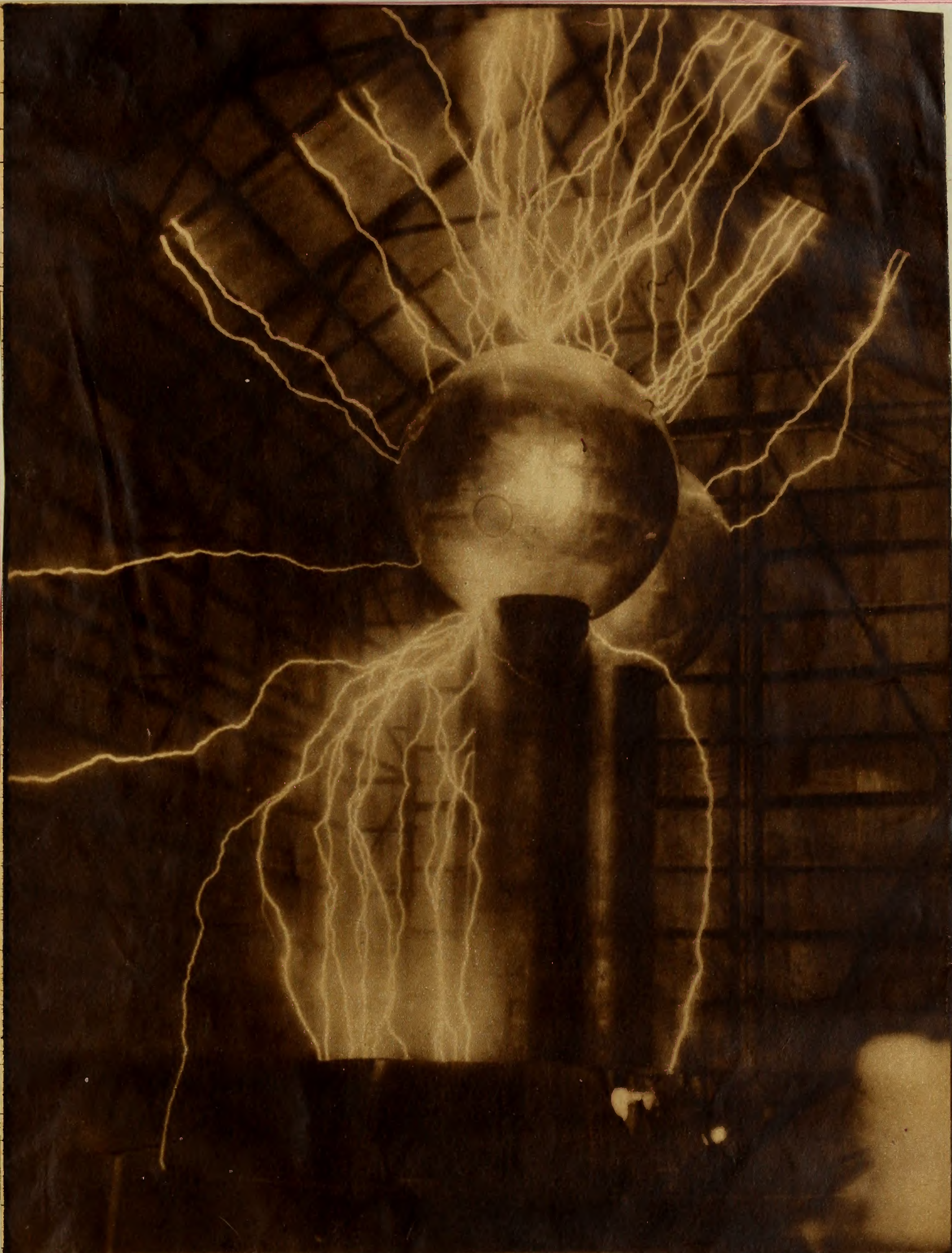
*Source unknown

Massachusetts Institute of Technology of the new Van de Graaf electrostatic generator which can develop a potential difference of 7,000,000 volts and which will be used for the bombardment of atomic nuclei.

Within a short time, the neutron, the positron, and the deuton have all been discovered. It is well to note in connection with these discoveries that it is given to the "young men to see visions"* and perhaps to the old men to "dream dreams".* What the future will bring forth no one can say, what particles or phenomena may appear no one can foretell, but there will certainly be thrilling and marvellous discoveries which will challenge the imagination of anyone interested in science.

* The Bible:- Joel 2: 28.

34-A



MAN'S MIGHTIEST WALLOP was recently unleashed at South Dartmouth when "Tech" scientists, rivalling nature, produced 7,000,000 volts of electrical energy with the new Van de Graaff electrostatic generator that may eventually be used to "crack" the atom. (At left), Looking up through the huge insulating column to the spherical terminal. (International News photo).

D. Summary.

1. The Electron.

This is the elementary negative particle which is found in the nucleus and also is supposed to neutralize the positive charge on the nucleus. It causes phosphorescence, generates heat, causes X-rays and can be deflected by a magnet.

2. The Proton.

The proton is the positive particle which is identified with the hydrogen nucleus. The number of protons in an atom determines its mass. While it is small in size compared with the electron, its mass is much greater.

3. The Neutron.

This is a recently discovered neutral particle, ejected from atoms and of high penetrating power. It is the only particle which produces no track. It is evident from its effect on the nuclei of other atoms, for when it does hit one, new substances are formed.

4. The Positron.

The discovery of this particle is so very recent that its nature is not fully known. It appears to be very much like an electron, except for its positive charge. It is not yet known whether it is ejected from the nucleus of an atom or made from a photon.

5. The Deuton.

This particle is the nucleus of "heavy hydrogen". Of a

charge equal to that of the proton, it proves to be twice as heavy. Combined with oxygen to form "heavy water", many strange things result. The particle itself is useful as a battering ram for atomic nuclei, one of the most effective projectiles of them all.

E. Table of Particles Making up the Atom.

Name of particle	Mass in grams	Dimensions in cm.	Charge
1. Electron	0.903×10^{-28}	2×10^{-13}	e or 4.770×10^{-10} E.S.U.
2. Proton	1.66×10^{-24}	1/1800 of electron	+ e
3. Neutron	1.0003 (?)	1.4×10^{-13}	0
4. Positron	----	----	+ e
5. Deuton	3.31×10^{-24}	----	+ e

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XXVI---The Nucleus I

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